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Article (Published Version)

Perception, 2002, volume 31, pages 287 – 296

DOI:10.1068/p3195

Is there a linear or a nonlinear relationship between rotation and configural processing of faces?

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Received 31 January 2001, in revised form 24 October 2001

Abstract. Research suggests that inverted faces are harder to recognise than upright faces because of a disruption in processing their configural properties. Reasons for this difficulty were explored by investigating people's ability to identify faces at intermediate angles of rotation. Participants were asked to discriminate blurred famous and unfamiliar faces presented at nine angles. Blurred faces were used to minimise featural processing strategies, and to assess the effects of rotation that are specific to configural processing. The results indicate a linear relationship between angle of rotation and recognition accuracy. It appears that configural processing becomes gradually more disrupted the further a face is oriented away from the upright. The implications of these findings for competing explanations of the face-inversion effect are discussed.

1 Introduction

It is well known that inverted faces are disproportionately difficult to recognise compared to other objects (Yin 1969; Valentine 1988). A variety of evidence now suggests that this is because the processing of information describing the configuration of facial features is impaired (eg Young et al 1987; Bartlett and Searcy 1993; Rhodes et al 1993; Lewis and Johnston 1997; Leder and Bruce 2000). In a previous study we demonstrated that scrambled inverted faces were no more difficult to recognise than intact inverted faces, whilst blurred inverted faces were not recognised above chance level (Collishaw and Hole 2000). Scrambling directly disrupts the facial configuration, whilst blurring obscures fine-detail local information. Our results therefore suggest that configural or holistic information is not normally used to recognise inverted faces, and that residual recognition of inverted faces reflects a featural processing route.

There are a number of competing explanations why configural information is difficult to retrieve from inverted faces. One theory explains our poor performance with recognising inverted faces in terms of a lack of expertise with upside-down faces. An alternative account of the inversion effect focuses on the complexity of faces, and suggests that they cannot be effectively normalised when viewed upside down. Diamond and Carey (1986) distinguish between first-order and second-order relational information. First-order relational information describes the basic configuration of a stimulus, and is used to classify a face as a face (eg eyes above nose above mouth). Second-order relational information reflects variations of this basic configuration and defines individual members within a stimulus class (eg wide set eyes for a narrow face). According to Diamond and Carey, people must be experts with a stimulus class if they are to be able to process second-order relational information. Thus, one possibility is that the inversion effect reflects people's lack of expertise with viewing upside-down faces, making complex configural processing difficult or impossible. The second possibility is that face recognition includes a processing stage, where the perceptual input is normalised (Rock 1973, 1988; Hamm and McMullen 1998; Jolicoeur and Humphrey 1998). According to this view, inverted faces must be normalised before further processing leading to the identity of the face is undertaken. Rock (1973, 1988) argues that faces must be mentally rotated to the canonical view, and that mental rotation mechanisms can cope with simple shapes (eg individual facial features), but fail with complex shapes (eg the whole face). If features can be rotated one at a time but not simultaneously, information about the configuration of multiple features would be impaired more than information about individual features, thus giving rise to the inversion effect.

We can test specific formulations of these two accounts by examining recognition of faces over a range of angles of rotation. In everyday life, people commonly see faces deviating to a small degree from an upright angle (eg people tilt their heads in conversation). However, people are likely to have little or no expertise with faces beyond a certain angle of rotation. For instance, it is unlikely that people have any more experience with faces presented at 100° than those presented at 180°. If a 'simple expertise' explanation is correct, then face recognition should suddenly become much more difficult as faces are rotated beyond the limits of our normal experience.

There are two alternative accounts of how limitations of normalisation lead to the inversion effect. First, it is possible that normalisation mechanisms fail altogether when processing configural information. Only faces presented at views fitting stored representations could then be processed configurally. This hypothesis predicts a nonlinear relationship between angle of rotation and accuracy of recognition of blurred faces. Alternatively, a linear increase in difficulty is expected if the accuracy of the representation of configural information depends on the amount of normalisation required. For example, the facial representation may become progressively distorted the further it is mentally rotated.

A number of researchers have examined the recognition and perceptual matching of faces presented at different angles of rotation between upright and inverted. Valentine and Bruce (1988) argued that a switch from configural processing to a featural processing strategy might be expected to lead to a nonlinear relationship between angle of rotation and recognition or matching performance. Valentine and Bruce compared performance over five angles of rotation. Only the linear relationship was significant in their analyses. However, the use of so few angles of rotation may have militated against higher-order trends being revealed. Bruyer et al (1993) used ten different angles of rotation, and examined participants' speed at making familiarity decisions. However, their design was relatively insensitive to the normal inversion effect. One possible reason for this is that only a small number of target and distractor faces was used, and the faces were presented repeatedly at the different angles of rotation. With repeated exposure, both sets of faces (targets and distractors) will become familiar. Additionally, the task may become one of picture recognition, rather than face recognition. This is also problematic, as the questions under consideration relate to hypotheses that are specific to face recognition.

Whilst Valentine and Bruce tested for a switch from configural processing of upright faces to featural processing of inverted faces, we suggest that featural processing is a characteristic of facial processing at all angles, and that the inversion effect is best described as a specific impairment of configural processing. Valentine and Bruce (1988) and Bruyer et al (1993) examined recognition and matching of normal faces. These tasks are likely to reflect the use of both featural and configural strategies. As local featural processing has been found to remain relatively unimpaired by inversion (eg Endo 1986; Searcy and Bartlett 1996; Schwaninger and Mast 1999; Collishaw and Hole 2000), the use of featural information may mask any discontinuity produced by a 'switching off' of a configural process, especially if a featural strategy is used in a compensatory manner. The aim of the current study is to focus specifically on the processing of configural information.

There are various possible experimental paradigms that might enable one to focus more specifically on configural processing of faces at different angles of rotation. At the outset, it is worth noting that there are several reasons for doubting whether any design can eliminate *entirely* the processing of local feature information, whilst leaving configural processing *wholly* unaffected. First, too little is known at present to define with precision what constitutes featural and what configural information. Second, it is unclear whether features and configurations are two separate types of information, or whether they are opposite ends of a continuous dimension. Furthermore, it is possible that there is a degree of overlap between the information that may be used by configural and featural processing mechanisms. However, there are a variety of experimental tasks and designs that predominantly reflect the influence of configural processing mechanisms or that allow us to minimise the influence of featural processing. We will assume that a better understanding of the relationship between orientation and configural processing of faces can be gained by making use of such designs.

Previous research that has focused on the processing of configural information in faces presented at different angles of rotation is contradictory. Sjoberg and Windes (1992) and Stürzel and Spillmann (2000) examined the processing of 'Thatcherised' and normal faces at different angles of rotation. The Thatcher effect is the gruesome impression that is created by inverting the eyes and mouth within the face (Thompson 1980). When Thatcherised faces are presented upside down, the faces no longer look particularly unusual. It has been argued that the basis for the effect is the distortion of the configural information used for the analysis of facial expression. If configural information cannot be used in inverted faces, then this would explain why inverted Thatcher faces do not look unusual. Sjoberg and Windes analysed response times in making an abnormal/normal judgment at six angles of rotation and found no evidence for a nonlinear relation between latency and angle of rotation. In contrast, Stürzel and Spillmann (2000) used the method of ascending and descending limits to ascertain at which angle the expressions of three Thatcherised faces changed from 'pleasant' to 'grotesque'. They report a fairly sudden change between 94° and 100° deviation from upright, and conclude that, as a face is rotated beyond this angle, processing switches from a holistic (or configural) mode to a componential one.

Schwaninger and Mast (1999) compared people's ability to detect featural or configural changes at seven angles of rotation in a sequential matching task. As expected, the featural changes were detected accurately at all rotations. For configural changes, the number of errors differed depending on the angle of rotation. These results are in line with our general view that the inversion effect reflects a disproportionate impairment of configural processing. The most errors were found at intermediate angles of rotation (90° – 120°). However, it is possible that this peak in errors is specific to the configural change used in their study. In particular, the configural dimension that was varied was the distance between the eyes relative to the distance between the mouth and the eyes.

The current study attempts to clarify whether there is a linear or nonlinear relationship between angle of rotation and the ability to process configural information in faces. The research discussed above focuses on configural processing of faces in two perceptual tasks. Our experiment focuses on the effects of stimulus rotation on the processing of configural information in a face-recognition task. The method used here for controlling for the effects of componential processing is to blur the stimuli faces to such an extent that local feature information is degraded, whilst more general configural cues carried at lower spatial frequencies are retained. There is considerable interest in the use of different spatial scales in the perception and recognition of faces. A variety of methods, including pixelisation, Gaussian blurs, and other low-pass and high-pass filters, have been used to examine the influence of different spatial scales.

Harmon (1973) demonstrated that pictures of famous faces could still be recognised even when faces were shown as part of 16×16 pixel images. Bachmann (1991) found that recognition rates dropped dramatically as the number of pixels used to make up faces was reduced from 18 to 15 (across the width of the face). Costen et al (1996) in reviewing the literature in this area concluded that information critical for face recognition is carried by spatial frequencies between 8 and 16 cycles per face width (equivalent to 16 to 32 pixels across the width of the face). Removal of frequencies above 16 cycles does not significantly impair recognition (presumably because even local feature recognition is unimpaired), whilst removal of all frequencies higher than 8 cycles per face width reduces performance to chance level (presumably because even the most general configural patterns can no longer be perceived). Collishaw and Hole (2000) showed that at a level of blur leading to a progressive attenuation of spatial frequencies beyond approximately 8 cycles per face width upright blurred faces were often recognised with reasonable accuracy, but inverted blurred faces were not recognised above chance level. It appears that, at this level of blur, featural information had been degraded, and that these faces elicited a predominantly (or wholly) configural processing strategy. In our current study we use the same stimuli with an equivalent level of blur. We assume that featural information is sufficiently degraded to allow us to focus on the effects of stimulus rotation on the processing of configural information.

In summary, our aim is to further specify the relationship between stimulus rotation and the use of configural information in a face-recognition task. In particular, we examine at what angle of rotation recognition performance for blurred faces is reduced to chance level. The experiment uses a familiarity decision task (famous versus unfamiliar), and assesses recognition performance at nine angles of rotation between 0° and 180° to provide greater sensitivity to a nonlinear effect than in some previous studies. Large numbers of target and distractor faces are used to avoid the problems of repeated exposure of experimental stimuli.

2 Method

2.1 *Participants and design*

Seventeen women and ten men, ranging in age from 19 to 52 years, participated in the study. Four further participants had been tested, but were excluded from the study for various reasons.[1] A within-subjects design was used. Each participant was presented with blurred faces at each of nine angles of rotation from upright (0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, 157.5°, 180°). Participants were asked to decide whether each face was famous or not famous.

2.2 *Materials and apparatus*

Faces of male, Caucasian, clean-shaven celebrities were scanned into a computer from magazines. The celebrities were famous for their work in a variety of domains, including TV, film, and politics. The target faces used here were selected from a set piloted on sixteen people for familiarity. Only faces identified by at least 75% of pilot participants were included. The mean identification rate for target faces was higher than 90%. Distractor faces were individually matched to the target faces on the basis of age, hair colour and hair length, and quality of image. These faces were selected from a set of Dutch celebrities, unknown in the UK. This controls for a number of factors that might otherwise distinguish celebrity and noncelebrity faces (eg quality of image, make-up, pose, expression, etc). 47 target faces and 47 distractor faces were used.

[1] These participants responded uniformly to stimuli presented at one or more angles of orientation. Analyses of the results including these participants (but adjusting d' values appropriately) did not differ in their findings.

All faces were blurred, with the Gaussian filter available in Photoshop. The same level of blur as used by Collishaw and Hole (2000) was selected—a filter with a radius of 10 pixels. As shown in the graph in the appendix, there was a progressive attenuation of the higher spatial frequencies in the blurred images. Nine versions of each face were then created by rotating the images in steps of 22.5° away from the upright. Half the images were rotated clockwise, and half anticlockwise. An example target face is shown at each angle of rotation in figure 1.

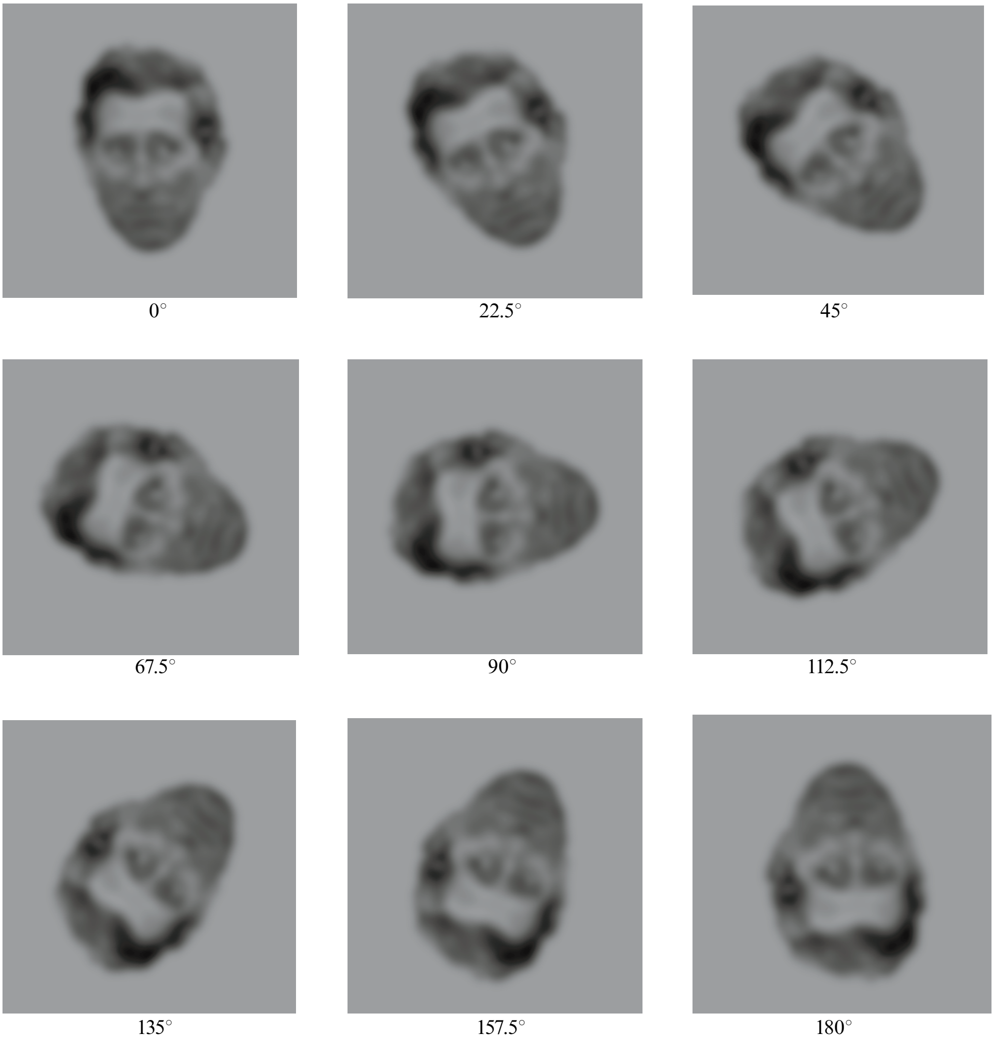

Figure 1. Recognition of blurred faces presented at nine angles of rotation (sample stimuli).

Faces measured 140 mm by (approximately) 165 mm. Participants were tested at a viewing distance of 60 – 70 cm. The images thus subtended about 12.15 deg horizontally when presented at upright. The faces were presented with the SuperlabPro 1.05 software (Cedrus Corp., San Pedro, CA, USA), which recorded participants' decisions and response latencies.

2.3 *Procedure*

Participants were given written instructions and four practice trials. They then received the block of 90 test faces. Each participant was shown 10 faces (5 targets and 5 distractors) at each of the nine orientations. The angle of rotation at which each face appeared was counterbalanced across participants.[2] Thus, each face appeared only once for each participant, but all faces appeared equally often at the nine angles of rotation for the group as a whole. Trials were presented to participants one by one in a random order. Stimuli were displayed for 3 s, and the participant pressed either the left or the right mouse button to indicate whether the face shown was a celebrity or not. A 3 s delay separated the end of one trial and the onset of the next. The accuracy and latency of each response was recorded.

3 Statistical analysis

d' scores were calculated and used as a measure of recognition accuracy in the statistical analyses. The procedure adopted for dealing with cases where d' is undefined (100% hits or 100% misses on signal trials; 100% false alarms or 100% correct rejections on noise trials) was to replace observed values of 0 or N_s hits, and 0 or N_n false alarms with 0.5, $N_s - 0.5$, or $N_n - 0.5$. Perfect performance would yield a d' of 3.29, and chance performance corresponds to a d' of 0. The percentage of correct responses in each condition is also reported. Analyses of reaction times were restricted to times for correct target trials, and mean + 2SD cut-offs were calculated separately for each angle of rotation to exclude outlying responses.

4 Results

Table 1 shows mean and standard deviation d' scores for faces at each angle of rotation. Accuracy at each angle of rotation is compared against that expected by chance. The results are in accordance with those of Collishaw and Hole (2000): upright blurred faces were recognised above chance level, whilst inverted blurred faces were not. In figure 2, the percentage correct recognition is plotted against angle of rotation, and the best-fit line for plotted accuracies is shown.

Table 1. Recognition accuracy (d') for blurred faces at nine angles of rotation.

	Angle of rotation/°								
	0	22.5	45	67.5	90	112.5	135	157.5	180
Mean d'	0.86	1.17	0.86	0.69	0.53	0.52	0.41	0.22	−0.02
SD	0.72	0.97	1.44	0.95	0.86	0.80	1.00	0.97	1.00
t_{26} [a]	6.25***	6.26***	3.09**	3.80***	3.19**	3.38**	2.11*	1.16 ns	−0.11 ns

[a] One-tailed t-tests comparing d' scores with 0 (the score expected by chance).
$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; ns, not significant.

A repeated-measures analysis of variance found a significant main effect of orientation on participants' d' scores (Greenhouse–Geisser corrected $F_{5.7, 150.0} = 3.75$, $p = 0.002$). Polynomial contrasts showed that only the coefficient for the linear component was significant ($F_{1,26} = 29.2$, $p < 0.001$). Quadratic ($p > 0.4$), cubic ($p > 0.7$) and all other higher-order trends ($p > 0.2$) were not significant.

An analysis of participants' correct trial reaction times (excluding extreme outliers) failed to demonstrate a significant main effect of angle of rotation (Greenhouse–Geisser corrected $F_{4.7, 121.9} = 1.34$, $p = 0.25$). Polynomial contrasts revealed a marginal linear effect ($F_{1,26} = 5.09$, $p = 0.03$). There were no significant higher-order trends ($p > 0.1$).

[2] The 90 faces were randomly divided into nine sets of 10 faces (5 targets and 5 distractors). Three participants were shown set 1 at 0°, set 2 at 22°, set 3 at 45°, ... set 9 at 180°, three participants were shown set 2 at 0°, set 3 at 22°, set 4 at 45°, ... set 1 at 180°, and so on.

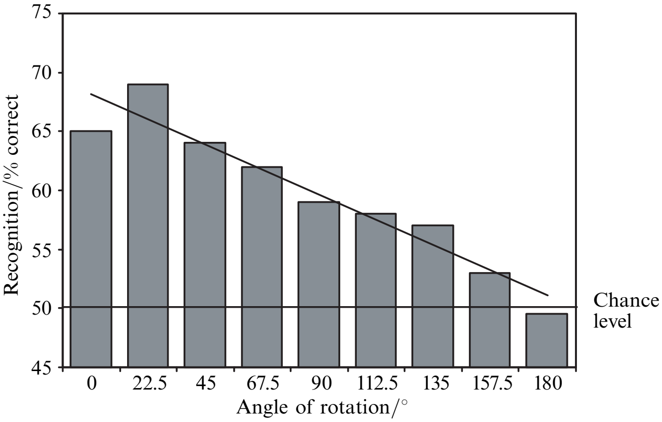

Figure 2. Recognition accuracy for blurred faces presented at nine angles of rotation.

5 Discussion

In our previous study we found that, at a level of blur equivalent to progressively attenuating spatial frequencies higher than approximately 8 cycles per face width, faces contain information sufficient for a configural mode of processing, but not for a featural analysis (Collishaw and Hole 2000). The results of this study, with images with the same level of blur, provide further evidence for these conclusions. Upright blurred faces were recognised well above chance. On the other hand, upside-down blurred faces could not be identified significantly above chance level, presumably because featural and configural routes of processing have both been disrupted.

These results support the belief that the images used in this study largely filtered out information necessary for a fine-grained featural analysis, and that our findings reflect more directly the relationship between configural processing of faces and angle of orientation. It appears that this relationship is a linear one: the further a face is oriented away from an upright view, the greater the difficulty in extracting configural information from the face, and hence level of accuracy gradually diminishes towards chance level. The current results suggest that configural processing as a whole is affected in a linear manner by disorientation.

The results of the polynomial contrast analysis of correct trial reaction times are not inconsistent with these conclusions. We found a marginally significant linear relationship between angle of rotation and reaction time, and there were no significant higher-order trends. However, the main effect of angle of rotation on reaction times was not significant. This may be due to the difficulty of the task. In particular, as faces are rotated further towards 180°, the analysis of correct trial reaction times becomes less meaningful, because the recognition accuracy for such faces was at, or approaching, chance level.

This experiment confirms the conclusion made previously by Valentine and Bruce (1988) that the inversion effect in face recognition reflects the operation of a linear or quantitative effect of angle of rotation on processing. However, the current study extends the findings from previous research by largely ruling out compensatory processes based on the analysis of local featural detail. The current study was also more sensitive to any nonlinear shifts in the effects of orientation by employing a greater number of angles of rotation. Finally, the current study avoided some of the methodological problems of previous studies that were based on the repeated exposure of target and distractor images.

Whilst our study provides evidence for a linear relationship between angle of rotation and the accuracy of retrieval of configural information from faces, it should be noted that it is possible that the processing of some specific configural cues may be influenced in a nonlinear manner by rotation (Schwaninger and Mast 1999).

One aim of the study was to examine why it is difficult to process inverted faces configurally. As mentioned above, Diamond and Carey (1986) have suggested that configural processing of faces relies on people's expertise with this stimulus class. According to this view, people are not experts at seeing upside-down faces, and so configural processing breaks down when faces are inverted. However, the linear relationship between angle of rotation and recognition accuracy is strong evidence that the inversion effect cannot be explained solely in terms of expertise. For example, it is hard to explain why faces at 112.5° and 135° rotation should be recognised at above chance level, whilst faces at 180° are not. It is unlikely that people have more experience seeing faces at these angles in everyday life. An important question is whether the current results can be reconciled with findings that expertise is a necessary requirement for configural processing to take place (Diamond and Carey 1986; Gauthier and Tarr 1997). Whilst expertise with faces may determine the distribution of view specific representations of faces, it appears that other factors (such as normalisation) must also be considered in order to fully explain the linear relationship between angle of rotation and face-recognition performance.

The results are consistent with a theory which holds that face recognition includes a stage of processing at which the perceptual input is normalised, and which produces output representations that can be matched against those held in memory (eg Rock 1973; Hamm and McMullen 1998). One possible mechanism for normalisation may be to mentally rotate faces to an upright position. However, the results are at odds with the hypothesis that normalisation of configural information fails categorically. Instead, one possibility is that normalisation is subject to a certain amount of error, especially for complex shapes, and that the amount of error in the normalised representation is proportional to the degree of normalisation. According to Rock, representations of less complex aspects of perceptual inputs (eg individual facial features) can be mentally rotated without much error, whilst representations of highly complex or subtle aspects of the input (such as configural or holistic information) will be significantly distorted as they are mentally rotated.

Whilst many authors suggest that faces are normalised for characteristics such as size and orientation (eg Hamm and McMullen 1998; Jolicoeur and Humphrey 1998), further research is needed to provide direct evidence for a normalisation stage in face recognition. Furthermore, other researchers have argued that there is no need to postulate such a processing stage, and have provided alternative explanations for the linear relationship between angle of orientation and peoples' performance in face-matching or face-recognition tasks. For example, Biederman and Kalocsai (1997) and Cooper and Wojan (2000) argue that face individuation requires the use of a precise metric specification and therefore relies on a coordinate coding system. Cooper and Wojan suggest that the discrepancy between input and stored coordinates increases linearly with angle of rotation, with the lowest activation levels for faces presented at 180°. Perrett et al (1998) and Ashbridge et al (2000) argue that disoriented faces are not normalised, but present evidence that the output of a population of face-responsive neurons will be linearly related to orientation owing to the statistical distribution of individual cells with particular orientation preferences.

6 Conclusions

The results of this experiment suggest that disoriented faces are difficult to recognise because of a progressive impairment of configural processing that is linearly related to the extent to which the input face has been rotated away from the upright view. It is argued that the inversion effect cannot be simply ascribed to a lack of expertise with non-upright faces, nor to an absolute failure of a mechanism that normalises disoriented faces. We have described several alternative explanations that may account for the linear effect demonstrated here.

Acknowledgments. We would like to thank Eugene McSorley for analysing the spatial content of our images, and for providing advice about the precise effects of the Gaussian blurs applied here. Simon Wallace and Karen Schepman provided helpful comments on earlier drafts of this paper.

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Appendix

The spatial content of four sample images used in this study was analysed with a program written in MatLab. The four images were blurred and unblurred versions of Prince Charles and Bill Clinton. For each image a fast Fourier transform was carried out. A 1-D plot of frequency by power was produced by separately averaging all the power at each spatial frequency across orientation. Figure A1 shows the results for blurred and unblurred versions of Prince Charles. The results for Bill Clinton were closely similar to those for Prince Charles, and thus are not shown here.

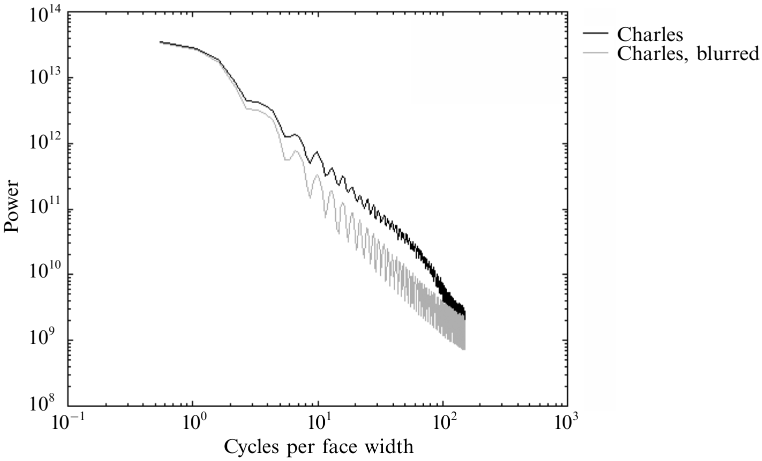

Figure A1. The effects of the blur procedure on the spatial frequencies contained in a sample target face.